

# PATENT SPECIFICATION

DRAWINGS ATTACHED

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## COMPLETE SPECIFICATION

### Improvements in or relating to Luminescent Diodes

We, SIEMENS AKTIENGESELLSCHAFT, a German Company, of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a licence may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to luminescent diodes, for example of an A<sup>III</sup>B<sup>V</sup>-material such as gallium arsenide.

The invention consists in a luminescent diode in which a carrier crystal body forming said diode has a first part of the surface of one zone of said diode shaped to form a concave reflector for radiation produced within the crystal at the diode junction, and the remaining part of the carrier crystal surface of said one zone forms a radiation exit surface, said first part of said carrier crystal surface being provided with a metal layer having good reflectivity, heat-conductivity and electrical conductivity, and said remaining part of said surface being provided with a reflection-reducing coating.

Thus, the invention avoids the need for an external concave mirror, remote from the semiconductor body of the diode, by utilising a part of the surface of the carrier crystal as a reflector, and the remaining part of the surface of the one zone as an exit surface provided with a reflection-reducing layer in known manner, to give the maximum possible emission of light focussed by reflection at the reflector surface acting as concave mirror. With such an arrangement, it is possible to ensure that almost the entire light output of the pn-junction inside the carrier crystal is radiated in a preferred direction (reflector axis). Due to its high efficiency, a luminescent diode constructed in this way is particularly suitable for use as a transmitter element in an optical electronic arrangement of the type in

which an electrical signal is converted into light and transmitted in the form of optical radiation.

The invention will now be described with reference to the seven exemplary embodiments illustrated schematically in Figures 1 to 7 of the accompanying drawings. In each Figure, a carrier crystal 1, for example of A<sup>III</sup>B<sup>V</sup>-material, preferably of gallium arsenide, forms one zone of the luminescent diode. Normally, such a diode is so constructed that the radiation produced by luminescence at the pn-junction passes out through the n-type zone of the diode, and therefore this carrier crystal advantageously consists of n-type gallium arsenide.

A zone 2, of the opposite conductivity type, forms a pn-junction region 3 within the crystal 1. A part 4 of the carrier crystal surface is shaped to act as a reflector to focus light through another part 5, of the crystal's outer surface, which thus serves as an exit surface. The reflecting surface 4 is provided with a layer 6, to increase the reflection, and this is a metallic coating, for instance of silver, copper, aluminium, or an alloy which is suitable to assist in conducting away the heat formed in the diode during operation, and also to act as a contact electrode to the diode zone formed by the carrier crystal 1. The reflecting surface 4 may be polished before the layer 6 is provided.

The radiation exit surface 5 is preferably substantially transverse to the reflector axis, in order that a focussed beaming of light can be projected in the direction of the reflector axis A, the desired direction of the optical signal transmission.

Due to the high refractive index of the gallium arsenide boundary surface with the air, total internal reflection occurs at an angle of incidence of approximately 17°, and

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therefore the radiation exit surface 5 is provided with a reflection-reducing layer 7, in accordance with known techniques.

Surfaces having the form of a part of one of the following geometric shapes have good beaming reflecting properties: a paraboloid, an ellipsoid, and a sphere. The beaming in the case of a paraboloid reflector surface is optimal when the pn-junction 3 lies in the vicinity of the parabolic focal point F within the carrier crystal, as shown in Figures 1, 2 and 3, whilst in the case of an ellipsoid reflector surface it is optimal with the junction in the vicinity of an elliptical focal point  $F_1$ , as shown in Figures 4 and 5. In the case of a spherical reflector surface, the pn-junction must lie between the centre M of the sphere and the reflector surface, as shown in Figures 6 and 7. The radiation exit surface 5 may be a plane or curved surface transverse to the reflector axis, and in the case of a curved surface this is curved in such a way that the emerging radiation is at least partially focussed in the direction of the reflector axis.

A. Where the reflector surface 4 is constructed in the form of an ellipsoid with the light-producing pn-junction in the vicinity of the one focal point  $F_1$ , it is particularly advantageous to form the radiation exit surface 5 as a spherical surface which is confocal to the second focal point  $F_2$ , as shown in Figure 5, so that almost the entire luminescent radiation is gathered at the second focal point  $F_2$ .

The pn-junction 3 must be arranged inside the carrier crystal 1, which forms one diode zone, and manufacture of the pn-junction can be effected by drilling a hole into the carrier crystal 1 along the reflector axis A, either from the direction of the reflector surface 4 or from the direction of the radiation exit surface 5. The hole should have a cross-section substantially smaller than the radiation exit surface 5, and is drilled to the depth required to permit the formation of a differently doped zone, and thus the pn-junction, at the necessary point. The axial drilling can be effected by means of electron beams, ion beams, or laser beams, or by means of etching with a gas- or liquid-jet. The differently doped zone 2, and thus the pn-junction 3, can then be produced at the desired position by means of alloying, diffusing, or bombardment with focussed ion beams.

The diode electrodes are contacted *via* a terminal E1 connected to the coating 6 on the carrier body 1, and a terminal E2 connected to the zone 2 by a wire which is electrically insulated from the crystal 1 and alloyed or in pressure contact with the zone 2.

The embodiment illustrated in Figure 1 has a reflector surface 4 in the form of part of a paraboloid RP, having a focal point F, and a flat radiation exit surface 5. Axial

drilling from the direction of the radiation exit surface 5 was effected to permit the production of a pn-junction 3 at F.

The embodiment shown in Figure 2 is similar to that shown in Figure 1, but has a curved radiation exit surface 5.

In Figure 3, the reflector surface 4 is part of an elongated paraboloid, and the focal point F is a distance  $a$  from radiation exit surface 5, which forms part of the surface of a sphere K of radius  $r$ , where  $r$  is less than  $a$ , so that the centre  $M_s$  of the sphere K lies on the axis A between F and the exit surface 5. The zone 2 and junction 3 are formed at F by axial drilling from the direction of the reflector.

Figures 4 and 5 show two embodiments each having a reflector surface 4 in the form of part of an ellipsoid RE having focal points  $F_1$  and  $F_2$ . In both cases, axial drilling from the direction of the radiation exit surface 5 was effected to permit the formation of the pn-junction 3 at  $F_1$ .

In Figure 4, the exit surface 5 is a flat plane, but in Figure 5, where the ellipsoid RE is elongated, i.e. highly eccentric, the exit surface 5 is a concave surface forming part of a sphere K whose centre  $M_s$  lies at  $F_2$ , i.e. the radiation exit surface is confocal to the second focal point.

Figure 6 shows an embodiment having a reflector surface 4 formed as part of the surface of a sphere K, centre M, and a flat radiation exit surface 5 between the reflector surface 4 and its centre of curvature M. The pn-junction 3 is formed at a point P between M and the reflector surface 4, in this case by formation of the zone 2 at the centre of the exit surface 5.

In the embodiment shown in Figure 7, the reflector surface 4 is part of a sphere K, centre M, and the radiation exit surface 5 is concave. The pn-junction 3 is formed at a point P between M and reflector surface 4, by axial drilling from the exit surface 5.

#### WHAT WE CLAIM IS:—

1. A luminescent diode in which a carrier crystal body forming said diode has a first part of the surface of one zone of said diode shaped to form a concave reflector for radiation produced within the crystal at the diode junction, and the remaining part of the carrier crystal surface of said one zone forms a radiation exit surface, said first part of said carrier crystal surface being provided with a metal layer having good reflectivity, heat-conductivity and electrical conductivity, and said remaining part of said surface being provided with a reflection-reducing coating.

2. A diode as claimed in Claim 1 or Claim 2, in which said one zone of said crystal is of n-type gallium arsenide.

3. A diode as claimed in Claim 1 or Claim 2, in which said first part of said surface

has the form of a part of the surface of paraboloid symmetrical about an axis on which the diode junction is situated substantially at the focal point.

5 4. A diode as claimed in Claim 1 or Claim 2, in which said first part of said surface has the form of a part of the surface of an ellipsoid symmetrical about an axis on which the diode junction is situated substantially at one focal point.

10 5. A diode as claimed in Claim 1 or Claim 2, in which said first part of said surface has the form of a part of a spherical surface symmetrical about an axis on which the diode junction is formed at a point between the centre of the sphere and the spherical reflector surface.

20 6. A diode as claimed in any preceding Claim, in which said remaining part of said carrier crystal surface of said one zone lies in a plane perpendicular to said axis.

25 7. A diode as claimed in any one of Claims 1 to 5, in which said remaining part of said carrier crystal surface of said one zone is curved symmetrically about said axis in such a way that the emerging radiation is at least partially focussed in the direction of said axis.

30 8. A diode as claimed in Claim 7 when dependant upon Claim 4, in which said remaining part of said carrier crystal surface of said one zone is a spherical surface which is confocal to the second focal point of said ellipsoid, and is located between said two focal points.

35 9. A diode as claimed in any preceding Claim, in which the diode junction is formed within said carrier crystal by the formation of the second zone of said diode at the required position in an axial hole having a cross-section small in relation to the radiation exit surface.

40 10. A diode as claimed in any preceding Claim, in which said layer on said first part of said carrier crystal surface is connected to one terminal electrode, and the second zone of said diode is connected to a second terminal electrode by a wire which is insulated electrically from the carrier crystal.

50 11. A diode as claimed in Claim 10, in which the connection between said wire and said second zone is effected by alloying.

12. A diode as claimed in Claim 10, in which the connection between said wire and said second zone is effected by a spring loaded pressure contact.

55 13. A luminescent diode substantially as described with reference to any one of Figures 1 to 7 of the accompanying drawings.

60 14. A method of manufacturing a luminescent diode in accordance with any preceding Claim, including the step of drilling an axial hole in said carrier body to a predetermined depth.

65 15. A method as claimed in Claim 14, in which said hole is drilled by an electron beam.

16. A method as claimed in Claim 14, in which said hole is drilled by an ion beam.

70 17. A method as claimed in Claim 14, in which said hole is drilled by a laser beam.

18. A method as claimed in Claim 14, in which said hole is drilled by etching with a gas jet.

75 19. A method as claimed in Claim 14, in which said hole is drilled by etching with a liquid jet.

20. A method as claimed in any one of Claims 14 to 19, in which the second zone of said diode is subsequently formed in said hole by an alloying process.

80 21. A method as claimed in any one of Claims 14 to 19, in which the second zone of said diode is subsequently formed in said hole by a diffusion process.

85 22. A method as claimed in any one of Claims 14 to 19, in which the second zone of said diode is subsequently formed in said hole by the bombardment of the exposed surface by a focussed ion beam.

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